IMPACT GARDENING, SPUTTERING, MIXING, AND SURFACE-SUBSURFACE EXCHANGE ON EUROPA. Cynthia B. Phillips and Christopher F. Chyba, Center for the Study of Life in the Universe, SETI Institute, 2035 Landings Drive, Mountain View CA 94043. phillips@seti.org

Introduction: Charged-particle interactions with materials at Europa's surface can produce biologically useful oxidants such as molecular oxygen and hydrogen peroxide, which could help sustain a biosphere on Europa. Irradiation of carbon-containing materials at the surface of Europa should also produce simple organics [1-5]. These oxidants and organics, if transported downward through the ice shell to a liquid water layer, could provide a significant amount of energy to sustain a biosphere. However, irradiation also destroys such materials if they remain exposed on Europa's surface [6]. Sputtering erosion and surface mixing through impact gardening act to change the preservation depth.

If sputtering dominates over gardening, then material is created and destroyed at Europa's surface much faster than it can be buried and preserved by gardening. However, if gardening dominates, this means that irradiation products can be buried beneath the surface by gardening, where they are protected from further radiation processing. We are investigating models of gardening on Europa's surface to determine which regime is most appropriate. The results of this work will also provide the expected regolith depth on Europa, of relevance for future Europa landing spacecraft.

Once material is preserved from the surface irradiation that would destroy it, it must still work its way down through perhaps a kilometer or more of Europa's icy crust before it could become biologically relevant to a putative ocean biosphere. We begin the investigation of the myriad transport mechanisms that would help bring material from the surface to the potential ocean. These mechanisms will also bring up material from the subsurface to the surface, with relevance for the detection of subsurface composition and potential biosignatures.

Previous Gardening Estimates: Previous estimates of the gardening rate on Europa have depended on various assumptions and scalings, often over orders of magnitude. An initial attempt at a gardening estimate [6] based on a lunar analogy resulted in a gardening depth of about 1-10 centimeters over an expected surface age for Europa of about 10 Myr [7,8].

A later estimate of Europa's gardening rate [4] relied heavily on a regolith depth estimate from studies of Voyager images of Ganymede [9]. It also used a mass flux for small particles from studies of planetary rings [10]. This work resulted in a gardening depth of ~1.3 m over a surface age of ~10 Myr [4].

We have previously attempted to update the gardening rate for Europa by using Galileo data. Our initial attempt [11] used the impactor populations in the outer solar system summarized by Zahnle *et al.* [7,8] combined with lunar regolith growth studies of Shoemaker *et al.* [12,13] and Gault [14] as summarized in Melosh [15]. Based on this approach, we estimated a gardening depth on Europa of about 0.67 meters over a surface age of ~10 Myr [11]

To get this initial estimate, we used a value for the slope of the cumulative crater distribution from [9], which came from lunar studies for craters below 1 km in diameter, but is also consistent with fragmentation cascade studies done for small objects [7].

To update this estimate using Galileo data, we attempted to scale down from the large crater distribution of Zahnle et al [7,8] to get a more relevant value for the slope of the crater distribution (a key parameter in our gardening model [11]).

The problem with this approach was that it required us to assume that the slope of the observed large crater distribution on Europa was continued all the way down to the small sub-meter scale craters that are responsible for gardening. Large crater events on Europa are so infrequent compared to Europa's young surface age that they are fairly irrelevant to the gardening depth (by which we mean the mixing depth averaged over the entire surface). Instead, it is the small, more frequent and widespread cratering events which produce the broken surface layer commonly called regolith on small, airless worlds.

New Gardening Approach: Our current approach follows the same gardening depth formalization as our previous work [11], but instead of scaling down from the large crater distribution, we are using the counts of small craters by Bierhaus et al. [16]. These crater counts allow us to determine a small crater distribution from observations rather than by scaling from large craters.

Although we still have to scale down from the craters observed by [16] in the Galileo data (which range in diameter from tens of meters up to a kilometer of so), at least the scaling is over fewer orders of magnitude than was required previously. Also, there appears to be a significant change in slope between small and large craters on Europa, which could be due primarily to the significance of secondary craters on Europa [16]. Since there are so few large primary craters on Europa, Bierhaus et al. [16] found that the majority of small craters on Europa's surface are actually secondary craters from these large impacts. Whether the small craters are primaries or secondaries, however, should not have a large effect on the mechanics of gardening and regolith formation.

Thus, we believe that our new approach, currently in progress, of applying the observed small crater distribution to the models of gardening and regolith formation developed in our previous work [11], will result in a definitive Galileo-era gardening depth estimate for Europa. Since it seems that the sputtering models are fairly mature at this point [4], once we have a final gardening estimate we can compare it to the sputtering estimates to see what the prospects are for the preservation of radiation products at Europa's surface.

Surface – Subsurface Exchange: Once material has been created through radiation processing at Europa's surface and buried below the radiation processing depth by gardening, the material must then make its way down to the ocean layer before it can become biologically relevant. By considering the number of formation models proposed for various geologic features on Europa's surface, we plan to estimate the amount of material that could be transported from the surface to the subsurface ocean layer, as well as the amount of material that could be brought up from a subsurface ocean to the surface or near-surface. We will present a preliminary overview of this work as well.

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